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Document Number 1

Entry 1 of 1   File: USPT   Aug 30, 1994

DOCUMENT-IDENTIFIER: US 5343284 A
TITLE: Imaging lidar system employing bistatic operation

ABPL:
An imaging lidar system is presented which is adapted to decrease the
backscattering at the receiver when a target is viewed in reflection and
to increase the backscattered reflection when the target is viewed in
obscuration by operating the airborne lidar imaging system bistatically
in the former case, and monostatically in the latter case. In accordance
with a first embodiment of the present invention, a retractible prism
and remote reflecting mirror are used to direct the laser transmitter
beam downward. The reflecting mirror is offset so that there is a finite
angle between the transmitter optical path and the path of the light
reflected back into the CCD framing camera. The angle can be varied by
moving the reflecting mirror along a track or rail with the appropriate
adjustment to the mirror so that the transmitter beam is completely
captured and directed downward to illuminate the area viewed by the
camera. In a second embodiment of the present invention, the camera is
placed on runners and displaced from the transmitter beam. A control is
inserted so that the transmitter optics are directed to the area imaged
by the camera.

BSPR:
Presently, cumbersome and time consuming wire line devices must be used
for detecting underwater targets from remote airborne locations. These
devices are lowered into the water and of course, are easily subject to
damage and loss. Also, wire line devices make target searching
relatively slow and can only detect targets without providing visual
imaging. An important and novel system for remote detection and imaging
of objects underwater (or objects obscured by other backscattering media
which are at least partially transmitting to light such as ice, snow,
fog dust and smoke) from an airborne platform has been described in U.S.
Pat. Nos. 4,862,257 and 5,013,917, both of which are assigned to the
assignee hereof and incorporated herein by reference. The imaging lidar
system of U.S. Pat. No. 4,862,257 utilizes a laser to generate short
pulses of light with pulse widths on the order of nanoseconds. The laser
light is expanded by optics and projected down toward the surface of the
water and to an object or target. U.S. Pat. No. 5,013,417 relates to an
imaging lidar system intended for night vision.

BSPR:
U.S. Ser. No. 565,631 filed Aug. 10, 1990 which is also assigned to the
assignee-hereof and fully incorporated herein by reference, relates to
an airborne imaging lidar system which employs multiple pulsed laser
transmitters, multiple gated and intensified array camera receivers, an
optical scanner for increased field of regard, and a computer for system
control, automatic target detection and display generation. U.S. Ser.
No. 565,631 provides a means for rapidly searching a large volume of the
backscattering medium (e.g., water) for specified targets and improves
upon prior art devices in performance as a result of having more energy
in each laser pulse (due to simultaneous operation of multiple lasers)
and a more sensitive detection system using multiple cameras. The

several cameras may be utilized to image different range gates on a
single laser pulse or several cameras can be gated on at the same time
to provide independent pictures which can then be averaged to reduce the
noise level and improve sensitivity. Both of these improvements result
in higher signal-to-noise ratio and thus higher probability of detection
or greater range of depth capability.

BSPR:
Airborne imaging lidar systems fielded to date have been monostatic. In
other words, the system's transmitter (laser) and receiver (camera)
optics are colocated and coaxial. In a monostatic lidar system, the
light scattered back from the gated area returns along the same path as
it started from the transmitter. This 180.degree. backscatter occurs at
a peak in amplitude, and thus represents a maximum which occurs in
backscattered light. This is the optimum arrangement for objects viewed
in obscuration. As described in "Marine Optics", N. G. Jerlov, Elsevier
Oceanography Series 14, p. 34, Elsevier, N.Y. (1976), this peak in
backscattering is symmetric around 180.degree.. The intensity of this
backscattering can decrease an order of magnitude at deflections as
small as +/-10.degree. from 180.degree.. As a result, the monostatic
imaging lidar systems of the prior art are not well suited for imaging a
target when viewed in reflection.

BSPR:
In accordance with a first embodiment of the present invention, a
retractible prism and remote reflecting mirror are used to direct the
laser transmitter beam downward. The reflecting mirror is offset so that
there is a finite angle between the transmitter optical path and the
path of the light reflected back into the CCD framing camera. The angle
can be varied by moving the reflecting mirror along a track or rail with
the appropriate adjustment to the mirror so that the transmitter beam is
completely captured and directed downward to illuminate the area viewed
by the camera.

BSPR:
In addition, two variations of these two embodiments are provided in
which first, the camera optics move in response to the movement of the
transmitter beam, and second, the camera optic are directed to view the
area illuminated by the laser transmitter as the camera moves away from
the location of the transmitter. In all of these preferred embodiments,
the platform for the transmitter (and/or receiver) is an airborne
system.

DEPR:
Referring first to FIG. 1A, and in accordance with the present
invention, it is shown that to decrease the backscatter by a factor of
ten (one order of magnitude) for observation of a target in reflection,
the transmitter (e.g., lasers) and receiver (e.g. camera) must be in the
bistatic mode with path separations in the water of 10.degree.. For a
decrease of a factor of twenty, a path separation of 40.degree. is
required. Although theoretically a decrease of close to two orders of
magnitude could be obtained with a 90.degree. angle, this would present
practical difficulties as will now be discussed with respect to U.S.
Pat. No. 3,527,881 to Blanchard. Blanchard discloses a method for
imaging underwater objects in which isolated portions of a video screen
eliminates "scattering" effects. Such a procedure will not lessen the
scattering observed, it can only prevent pixel drain, a far less
significant source of noise. Blanchard asserts that the "source target
sensor angle" must be ". . . maintained . . . near 90.degree., which has
been determined to be the ideal angular space relationship to obtain
minimum backscatter". As discussed, FIG. 1 shows a minimum backscatter
point at 90.degree.. But this is for an all underwater system. The
practical difficulties in applying this all underwater concept are cited
in "Blue-green high powered light extends underwater visibility"
Kornstein, E. and Wetzstein, H., Electronics, Oct. 14, 1968 (see Figure
on page 147) and on FIG. 2 herein (where a monostatic and bistatic
system are shown), with the bistatic system operating at the "ideal"
90.degree. separation of transmitter and receiver. Kornstein et al.
state that "bistatic operation is preferable but impractical, so

monostatic is used . . . " Kornstein et al. clearly understood the
impracticality of attempting to separate transmitter and receiver by
90.degree. which would involve having to move large structures separated
by hundreds of feet through the water, with cabling and the requirement
to have these units always at the 90.degree. orientation.

DEPR:
Because of the 90.degree. angle requirement, and to minimize the light
path in the water, .PHI.' is 45.degree. and Sin .PHI.'=0,707; n' is the
refractive index for water, 1.33 and n is the refractive index for air,
1.00. Then, Sin .PHI.' is 1.33(707), and Sin .PHI. is 0.94031, and
.PHI.'=70.5.degree.. .PHI., the angle of inclination is therefore
19.5.degree.. This is a very low inclination to the surface of the
ocean. It has consequences which make the fielding of an airborne laser
system imaging a below water object at the 90.degree. angle unworkable.

DEPR:
Referring now to FIG. 12, a spherical Lambertjan reflection 220 oriented
with coordinates at the sphere center 221, vertical axis 222 and two
horizontal axes 224 and 225. The sphere 222 is illuminated by a lidar
transmitter 226 with light transmitted toward the sphere along axis 224.
This light produces an illuminated area 226 on the sphere. The shadow
227 is the half of the sphere which is not illuminated by the laser 226.
The receiving camera is positioned in the plane determined by axes 225
and 224. The angle .alpha. is the angle between the laser beam axis and
the orientation of the imaging camera. If the Lambertjan reflectivity is
R.sub.o, the light seen by the camera is given by Equation 3.

DEPR:
Referring to FIGS. 2A-B, 3A-B and 4A-B, the effects of separating the
transmitter and receiver are shown wherein two lidar systems are seen
operating side by side in a monostatic mode (FIGS. 2A, 3A and 4A) and a
bistatic mode (FIGS. 2B, 3B and 4B). In FIGS. 2A, 3A and 4A, the lidar
system with pulsed laser transmitter 10 and rated intensified charge
coupled device (ICCD) camera 12 (FIG. 4A) is illuminating and viewing a
target 14 underneath the ocean surface. The illuminating light 16 and
returned light 18 are coaxial; that is, the scattering angle of the
returned light is 180.degree. (with respect to the Zenith direction).
FIG. 2A is a graph 20 taken from FIG. 1A, showing that the light
backscattered from the ocean surrounding the target is at a maximum, and
this is reflected in trace 22 across one of the video frames 24 (see
FIG. 3A) from the illumination of target 14 by a single pulse. The trace
22 taken across this video frame 24 shows a level of "noise" 26
representing return from the sea water, and a "signal" 28 representing
return from the target.

DEPR:
Referring now to FIGS. 2B, 3B and 4B, the bistatic system consists of a
separately located laser transmitter 30 and camera 32. A target 34 is
shown at the same depth and is physically identical to target 14. The
effect of the separation of camera 32 and laser transmitter 30 is shown
in the graph 36 (FIG. 2B). Light 38 scattered back from the illuminated
area toward the transmitting laser is at the same intensity as the light
received at the camera of the monostatic system, and this is shown as
point 40 on graph 36. However, the light received at the bistatic camera
returning along path 42 at an angle .PHI. from the path 44 of the light
transmitted downward is of lower intensity, as represented by the point
46 on graph 36. A trace 48 across the video frame 50 corresponding to
this situation (FIG. 3B) shows a decreased "noise" level 52 and a
"signal" 54 which is comparable to the signal 28 which was coaxial with
the illuminating light beam in the monostatic case (see FIG. 3A). The
reason that signals 54 and 28 are roughly equal in magnitude is that the
target is a diffuse lambertjan reflector. If the target had been a
specular reflector of high reflectivity (e.g., a mirror) directed back
at the transmitters 10 and 30, the signal 28 would have been relatively
intense, but the signal 54 would have been negligible. Note also that in
accordance with this invention, the bistatic system (FIG. 4B) can be
configured so that the laser transmitter 30 illuminates the same volume
viewed by the camera 32 (as best shown in FIG. 9).

DEPR:
Referring to FIGS. 5A-B, 6A-B and 7A-B, a comparison between the
monostatic (FIGS. 5A, 6A and 7A) and bistatic (FIGS. 5B, 6B and 7B)
imaging of targets in obscuration is shown. In the case of monostatic
operation, the transmitted light 60 and backscattered light 62 are
coaxial; that is, the light 62 returns to the camera along the same path
that the pulsed illuminating light 60 arrived. Thus, the scattering
angle is 180.degree.. This is the point for maximum scattering return
from the ocean as shown by the graph 64 in FIG. 5A. The ICCD camera gate
is timed to observe the volume 66 which is below the object 68 to be
observed. Thus, the object 68 is seen in obscuration, since all light
which would have returned from the imaged area 66 to the camera, and
passing through the target will be blocked or obscured. This appears on
the video screen 70 as a dark spot 72 which is highlighted by the
surrounding backscatter originating from that part of 66 not obscured by
the target above it. The trace 74 is plotted showing the surrounding
"noise" 76 and signal 78. In this instance, contrast is provided by the
value of the surrounding backscattered light, so that in this case the
noise becomes the signal and the signal is merely the absence of noise.
For the bistatic case, (FIGS. 5B, 6B and 7B), the backscatter available
to provide contrast with the absence of signal from the obscured region
is reduced thereby decreasing the effective "signal" to "noise" ratio.
In this bistatic case, the pulsed laser illumination 80 illuminates the
area imaged by the ICCD camera. The light returns at 82 to the camera
which is now no longer coaxial with the pulsed laser transmitter. The
angular separation of the light rays is .PHI.. The light which would
have returned to the camera through the space now occupied by the target
87 is obscured. An obscuration volume 86 results similar to 66 in the
monostatic case. As can be seen from referring to graph 86, the
intensity of the backscatter is reduced, providing lesser contrast with
the shadow area caused by the obscuration 88. This can be seen on the
video frame 90. A scan 97 across this frame shows the ambient
backscatter 94 decreased, while the signal level 96 which is associated
with the target obscuration remains relatively constant, roughly
equivalent to 78.

DEPR:
Referring to FIG. 8, a first preferred embodiment for achieving bistatic
configuration for an imaging lidar system is shown generally at 98
wherein the transmitter and receiver are mounted for monostatic
(coaxial) sensing; with the addition of a movable mirror to alter the
trajectory of the pulsed light rays from the transmitter. The pulsed
laser transmitter 100 and ICCD camera 102 are mounted on an aircraft
airframe 104. A rail 106 is provided for a housing 108 of a turning
prism and output beam steering optics 110 (e.g. mirror) so that the
location of the effective origin of the output pulse can be varied. A
control coupling 112 for the output optics is provided with input from
the aircraft altimeter, so that the pulsed laser transmitter can
continue to illuminate the volume of the ocean viewed by the ICCD
camera, as altitude and distance between transmitter and receiver are
varied (see U.S. patent application Ser. No. 420,247 which has been
incorporated herein by reference). The transmitted light pulses are
initially directed away from a 180 degree trajectory by a first prism
113 and then directed to beam steering optics 110 by a second prism 114.
The redirected output beam 115 is transmitted downwardly and returns to
the camera 102 as the backscattered pulse 116. Of course, housing 108 is
movable and steering optic 110 is pivotable to alter the trajectory of
the transmitted pulsed light as desired. Moreover, the mirror 113 may be
removed or disengaged to permit conventional coaxial (monostatic)
operation.

DEPR:
Turning now to FIG. 9, alternative arrangements for both bistatic and
monostatic imaging lidars are shown mounted on a helicopter 118. In a
first of these embodiments, a pair of spaced receivers 120 and 122 are
used in conjunction with a transmitter 124 wherein receiver 120 is used
in a bistatic mode and receiver 122 is used in a monostatic mode. As
discussed in detail above, the bistatic arrangement may be useful for

detecting targets in reflection. In this configuration the camera 120 is physically separated in the horizontal plane from the laser beam projection optics 124 and their relative lines of sight are tilted to intersect at the target search depth. In this case, the volume backscatter angle is not 180.degree. (with respect to the zenith direction) but is less than 180.degree.. The result will be appreciably reduced backscatter light levels from the water 126 volume but no reduction in the target 128 reflection intensity. Thus, the SNR will be improved by avoiding the strong peaking of light backscatter at 180.degree.. As also mentioned, for shadow detection, the coaxial mode (180.degree.), and hence camera 122, are preferred since this gives the highest SNR for that mode. Thus, the system of FIG. 9 employs two sets of cameras 120, 122, one camera (e.g., 122) near the laser for optimized shadow detection and one camera (e.g., 120) separated for optimum reflection detection. Also, and for increased flexibility, camera 120 may be mounted on rails or rollers 125 so that it will be movable in the horizontal direction and the distance between transmitter 124 and camera 120 may be easily varied. In still another alternative embodiment, camera 122 may be removed and only movable camera 120 used. Camera 120 would then be movable between a first position coaxial with transmitter 124 (monostatic) and a plurality of second positions horizontally displaced from transmitter 124 (bistatic).

DEPR:
In still another alternative embodiment shown in FIG. 10, the electronics 130 for the gated camera are mounted near the laser transmitter 124 in the lidar system housing 132. When bistatic viewing is desired, a bundle of optical fibers 134 terminating at horizontally displaced receiving optics 136 is used to transmit received pulses of light to the lidar system camera sensor for detection. Of course, fiber optics may also be used conversely. In this latter case, element 136 comprises a projector; element 130 comprises the laser transmitter and element 124 comprises the receiver. Thus, the transmitter 130 will transmit pulses of light along at least one optical fiber 134 for projection downwardly through projection optics 136. Reflected pulses will then be received by receiver 124.

DEPR:
Referring now to FIG. 11, still two additional embodiments of the present invention are schematically shown. In a first of these additional embodiments, the airborne platform 150 (i.e., helicopter) includes a lidar system 151 having gated camera receiver 152 conventionally positioned for 180 degree viewing. In accordance with the present invention, the pulsed laser projector 154 is displaced horizontally from receiver 152 which is housed in a discrete vehicle 156 pulled along by platform 150 using a suitable cable 158. Vehicle 156 may be towed by platform 150 through the air or under water 170. Preferably, the pulsed laser transmitter 160 is actually housed in lidar system 151 with an optical fiber running along cable 158 so as to optically interconnect transmitter 160 to projector 154. Fins 162 are provided on vehicle 156 for stabilization purposes. As is clear from a review of FIG. 11, the towed transmitter vehicle 166 will provide a field of view 164 which is angled (when compared to the field of view 166 provided by receiver 152) so as to result in the lidar system 151 viewing the target 168 (under water 170) at a bistatic angle.

DEPR:
In a second embodiment of these alternative embodiments, element 152 comprises a pulsed laser transmitter and element 160 comprises the gated camera electronics with a bundle of optical fibers running along cable 158 to receiving optics 154 on towed vehicle 156.

DEPR:
In still other variations of the embodiments of FIG. 11, the actual pulsed laser transmitter or gated camera receiver may be housed in the towed vehicle 156 (thus, element 154 would function either as a transmitter or receiver). Communication between computer control means in the lidar system 151 on airborne platform 150 and either of the transmitter 154 or receiver 154 on vehicle 156 may be accomplished by

any known hardwired technique (e.g., along towing cable 158) or wireless technique (e.g., radio waves).

DEPR:
It will be appreciated that a lidar imaging system that has been described above has been described with improved ability to image undersea targets, and provide a better signal to noise ratio and probability of detection. Of course, any desired imaging lidar system may be employed including systems incorporating multiple lasers, multiple cameras, etc.

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Document Number 3

Entry 3 of 11   File: USPT   Nov 14, 1995

DOCUMENT-IDENTIFIER: US 5467122 A
TITLE: Underwater imaging in real time, using substantially direct
depth-to-display-height lidar streak mapping

ABPL:
An imaging system for detecting the contents of a turbid medium, such as
water or air, which is at least partially transmissive of light. The
system includes a light source for producing a series of discrete
fan-shaped pulse beams which are substantially uniform in intensity or
have been peaked at the edges of the fan to illuminate sections of the
medium, a streak tube with a large photocathode for collecting the
maximum amount of light from weak returns, a field-limiting slit
disposed in front of the photocathode for removing multiply scattered
light, a large aperture optical element for collecting and focusing the
reflected portions of the pulse beam on the field-limiting slit and the
photocathode, and an array of detectors. A volume display of the medium
is generated by translating the transmitter and receiver normal to the
longitudinal axis of the pulse beam to illuminate adjacent sections of
the medium, and combining the sections to provide a volume display. All,
or substantially all, of the light returned from each pulse beam is
utilized. Vehicle motion is used to provide the scan of the pulse beam.

BSPR:
This invention relates generally to an imaging system for detecting a
target in a turbid medium. More particularly, this invention relates to
a system for detecting an underwater target using lidar.

BSPR:
Several techniques have evolved over the years for overcoming the
problems associated with detecting targets in a light scattering medium.
One technique utilizes a narrow beam from a pulsed laser, such as a
doubled YAG, to scan the ocean. Generally, the beam transmitter and the
receiver aperture, which must be quite large to collect sufficient
energy, are scanned together, using scanning mirrors or other devices
such as prisms. The energy received from each pulse is detected with a
photomultiplier, or similar quantum-limited device, and the resulting
signal is amplified with a logarithmic response amplifier, digitized,
and then processed. Because the pulses are short, typically 10
nanoseconds, the detection electronics must be very fast, digitizing at
200 MHz or faster. Since the pulse rate is low, the processing rates
required to analyze the data from each pulse are within the state of the
art. Such methods require the use of mechanical scanners that are slow
and difficult to build, particularly if they are to be mounted on
aircraft. In accordance with a primary advantage of the present
invention, the need for fast digitizing electronics and mechanical
scanners is eliminated.

BSPR:
There are numerous drawbacks associated with the range gating technique.
Specifically, range gating does not allow utilizing all, or
substantially all, of the information returned from each pulse to create
three-dimensional data sets. Rather, in such prior art systems, a volume

of the medium is illuminated and by range gating, a specific section of the illuminated medium is selected. Thus, the signal above and below the range gate is rejected. Consequently, of the energy transmitted into the volume of the medium, only a small amount of the return is used. Additionally, a three-dimensional data set cannot be created from a single pulse. Rather, three-dimensional information can only be obtained by collecting many pulses, during which time the aircraft, or other vehicle must remain stationary. A large multiplicity of shots is required to create an image, thus wasting energy from the <u>laser</u>.

BSPR:
Despite the availability of such techniques, existing <u>lidar</u> systems are limited by the size of the receiver optics that can be used in a scanner. Generally, the light reflected from targets which are deeply submerged or are submerged in a very turbid medium is weak. Although large aperture optics can aid in maximizing the amount of light collected from weak returns, the size of the optics that can be used in a scanner is restricted by the size of the moving prisms or mirrors. Such cumbersome mechanisms can be eliminated, as in the present invention, by utilizing the motion of a vehicle, a boat or an aircraft carrying the system so that the dimensions for scanning can be reduced to one. However, the scanning problem is still formidable and restricts the size of the apertures that can be used. Moreover, volume scanning systems are very expensive, and require considerable power and weight. Consequently, the ability to install such systems in aircraft or other vehicles is restricted.

BSPR:
What is needed is an imaging system which provides an accurate and reliable image of an underwater target, eliminates the problems associated with mirror scanning and utilizes all, or substantially all, of the information returned from each pulse to eliminate wasting energy from the <u>laser</u>.

BSPR:
In operation, a single pulse beam is emitted to illuminate a section of the medium. A large aperture optic collects the back reflected portions of the pulse beam and focuses the reflected portions on a field-limiting slit. The field-limiting slit, located in front of the photocathode, rejects multiply reflected light. A lens, positioned between the field-limiting slit and the photocathode, reimages the image on the field-limiting slit onto the photocathode. Coupled to the streak tube is an imaging detector, typically a CCD, which detects signals generated by the streak tube in response to the reflected portions of the pulse beam impinging on the photocathode. Other imaging detectors, such as a TV camera or photodiode array may also be used To obtain a volume <u>display</u> of the medium, the generating means is moved normal to the longitudinal axis of the pulse beam so that each pulse illuminates adjacent sections of the turbid medium. A volume <u>display</u> of the medium is thus generated by combining the returns from adjacent sections of the medium. All, or substantially all, of the light returned from each pulse is utilized.

BSPR:
The photocathode on the streak tube is a thin strip behind a field-limiting slit on which the illuminated strip of the ocean, or scattering medium, is imaged by the receiver optics. When the <u>laser</u> beam pulse, typically a few nanoseconds in duration, returns to the receiver from the surface of the water, the electronic sweep of the tube is initiated, so that the following time history of the returning signal spread across the lateral surface of the tube anode is then a record of the reflection from the medium itself and from any submerged bodies in the medium, such as mines or submarines, including the reflection from the top surface of such objects and of the shadow below them. Because the slit cathode is long and covers the width of the ocean illuminated by the fan-shaped beam from the <u>laser,</u> the image on the anode phosphor or area detector is a wide vertical section of the ocean. In addition to imaging objects immersed and floating in the medium, the invention also applies to imaging objects on the bottom and to obtaining a profile of bottom topography that may be the only way to distinguish silt covered

objects, such as archaeological remains lying on the bottom, from the
bottom itself.

BSPR:
The invention described herein can be employed, for example, from a
fixed wing aircraft or helicopter, from boats on the water surface, or
from submerged vehicles for search at great depths. The invention is not
exclusively restricted to use on oceans or lakes, but is useful in
probing the contents of any turbid media through which light can pass,
even if absorbed and scattered, as long as some return can be obtained.
For example, the invention can be used to detect a target in air. The
items described in the following description are applicable to water
probing, but there is no reason that the concept cannot be applied to
the analysis of smaller volumes using very short laser pulses,
picoseconds duration for example, since the streak tube can capture such
time intervals.

BSPR:
The image on the anode can be photographed by means of a CCD camera or
similar device, particularly by logarithmic area array CCD-like
detectors, which is read out slowly compared to the fast duration of the
returning signal. The anode can also be replaced by a thinned backside
illuminated CCD. This enables one to view the phenomena on a cathode ray
screen directly, or after encoding the signal, to enable one to process
such images to obtain enhanced imagery through various means common to
those versed in the art of enhancement, such as subtracting the mean
return from the recorded ocean section. The subsequent display of such
ocean sections can be manipulated by adding many sections together to
provide a three-dimensional view of the underwater scene. Such
three-dimensional data sets, obtained by moving the sensor system normal
to the fan beam between each exposure so that each section is from an
adjacent section of the ocean, provide the ability to enhance detection
and reduce false alarms by rejecting images, such as fish, that might
not be apparent in any single section image. All of the light returned
is utilized in creating three-dimensional data sets, thus not wasting
energy from the laser.

DRPR:
FIG. 5 is a schematic diagram of the laser and the projection optics of
the preferred embodiment shown in FIG. 2; and

DEPR:
A volume display of the medium is generated by translating the
transmitter and receiver normal to the longitudinal axis of the
fan-shaped pulse beam to illuminate adjacent sections of the medium, and
combining the sections to provide a volume display. All, or
substantially all, of the light returned from each pulse is utilized to
create three-dimensional data sets. The motion of the vehicle is used to
provide the scan or motion of the fan-shaped pulse beam.

DEPR:
Normally, laser beams are non-uniform in intensity, with a maximum
intensity at the center of the beam and a minimum intensity at the
outermost edges of the pulse beam. This can be changed by applying
tapered coatings to the laser mirrors, or by the use of optical means
external to the laser. An optical invertor, comprised of a series of
lenses and a diamond-shaped mirror arrangement, enhances the intensity
at the outer portions of the pulse beam by optically inverting in one
dimension along the fan width the intensity pattern of the pulse beam.
The result is a pulse beam which compensates for the effect caused by
longer paths at the ends of the fan to produce a signal return that is
substantially uniform in intensity.

DEPR:
FIG. 1 shows a typical configuration of an aircraft 10, employing the
present invention to detect underwater targets. The invention can also
be used to detect targets in other turbid media, such as air. The
invention can also be deployed from a vehicle such as a helicopter, a
boat, or if searching at great depths, a submerged vehicle. A narrow,

fan-shaped pulse beam 12 is projected from the transmitter to the water below, with the longitudinal axis of the pulse beam 12 normal to the direction of flight. The pulse beam 12 illuminates a thin section in the water. Coverage of a volume of the water is obtained by issuing a series of discrete pulse beams 16-18 to illuminate adjacent sections of the water. After processing the successive slice images, the sections can be displayed to show a scan through a volume of the medium. Thus, the motion of the vehicle carrying the system is used to provide the scan of the pulse beam. The pulse rate to generate the series of discrete pulse beams is set by the aircraft velocity. In general, the pulse rate may be high and the beam width on the water surface narrow compared to the resolution determined by the imagery detector pixels. This is done to preserve temporal resolution, which can be reduced if the spatial width becomes large. In order to reduce the number of readouts of the CCD, the pulses can be accumulated on chip.

DEPR:
FIG. 2 shows a block diagram of the preferred embodiment of the invention. A timing unit 20 initiates the probing sequence by causing a laser 22 to emit a narrow, fan-shaped pulse beam 12 to illuminate a thin section in the water. After the Q-switch 84, shown in FIG. 5, in the laser 22 has closed, causing the laser to fire, the timing unit 20 initiates the variable delay unit 24. The variable delay unit 24 issues a delay pulse 26 to initiate the receiving unit. In order to insure that the delay is correct, a detector 28, such as a photomultiplier, is used to sense reflected portions 30 of the pulse beam. The timing unit 20 measures this time and resets the variable delay unit 24 to insure that the next delay pulse 26 is correct. Since the delay is variable, the invention can be operated at different aircraft altitudes.

DEPR:
The CCD detector array 48 is set to receive the image, before it arrives, by reading out the preceding frame. Once the sweep generator has completed the voltage rise and resets, a command is issued to the video control 52 to read the image on the CCD. The data is then passed to a processor 54, or directly to a cathode ray tube display 56, where a waterfall like display of the section of the ocean probed by the pulse beam 12 can be seen. Typical images are that of a water surface 58, a reflecting object 60, and a shadow from the reflecting object 62.

DEPR:
The subsequent display of such ocean sections can be manipulated by adding many sections together to provide a volume display of the underwater scene. Specifically, the sensor system is moved normal to the longitudinal axis of the pulse beam 12 between each exposure to illuminate adjacent sections of the ocean. The adjacent sections are then combined to obtain a volume display.

DEPR:
As described, the present invention would only be able to probe deep depths at night because of solar illumination. For the system to operate in the day, narrow band interference filters 124 are required. The filters 124, placed in front of the photocathode 32 of the streak tube 34, are designed to pass the wavelength of the laser and block all other wavelengths. The combination of the filters 124 and the short time each element in the detector array 48 sees photoelectrons 110, typically 5 nanoseconds thereby resolving 0.56 meter in depth, would insure that no more than a few background photoelectron count in any pixel would be obtained.

DEPR:
FIG. 3 shows a timing diagram of signals obtained from the reflected portions 30 of the pulse beam. The time history of the reflected portions 30 of the pulse beam comprises a record of the reflection from the medium itself, and from any submerged bodies in the medium, such as mines or submarines, including the reflection from the top surface of such objects and of the shadow below them. Because the part of the ocean illuminated by the pulse beam 12 is limited to a very thin section, the image on the phosphor layer 46 is a wide vertical section of the ocean.

The image can be photographed by means of a CCD camera or similar
device, particularly by logarithmic area array CCD-like detectors, which
read out slowly compared to the fast duration of the returning signal.
Consequently, the phenomena on the cathode ray tube <u>display</u> 56 can be
viewed directly, or the image can be processed by a processor 54 to
obtain enhanced imagery after the signal has been encoded. For the
latter, various common enhancement means, such as subtracting the mean
return from the recorded ocean section, can be utilized.

DEPR:
A diagram of the beam distribution on the MCP, phosphor and CCD is shown
in FIG. 4. The task of detecting the various components out of the
return requires an analysis of the waveforms, such as those shown in
FIGS. 3(a)-3(c), over the width of the fan. This analysis is enabled by
the principle embodiment of the invention that utilizes the streak tube
to present a spatial <u>display</u> of all parts of the fan beam as a map of
position versus time, or depth.

DEPR:
The <u>laser</u> and the output projection optics are depicted in detail in
FIG. 5. The <u>laser</u> required for the <u>lidar</u> of this invention is a typical
Q-switched <u>laser</u> that can produce pulse widths of the order of 5 to 15
nanoseconds. For purposes of illuminating the ocean and penetrating it,
wavelengths in the vicinity of 470 nanometers are optimum. In very
turbid water, however, yellow matter reduces the penetration at this
wavelength so that the optimum wavelength can be as long as 532
nanometers. Applicable <u>lasers</u> are doubled Nd-YAG, or Nd-YOS, Excimer
<u>lasers</u> using the C-A transition in XeF, and Copper vapor. All of these
can provide considerable power, in the order of joules/pulse at the
reasonably high rates required for observations from aircraft. Diode
pumped Nd-YAG for example could provide 1 joule at 30 Hz.

DEPR:
Shown in FIG. 5 is a typical diode pumped YAG <u>laser,</u> consisting of the
YAG rod 74, diode pumps 76 with a reflector 78, and an output coupling
mirror 80 forming the resonant cavity of the <u>laser</u>. The diode pumps 76
are driven by a diode driver 82 triggered by the timing unit 20. When
the rod 74 has been exposed to the pump energy and is maximally excited,
the Q-switch 84 is opened and the lasing action sweeps through the
excited states to produce an intense short pulse. These <u>lasers</u> commonly
emit in the infrared, 1.06 micrometers. However, a nonlinear crystal in
the path of the beam 86 can be arranged so that the frequency of the
radiation is doubled to give the desired wavelength at 0.53 micrometers.

DEPR:
The output of the <u>laser,</u> for the energy levels required, will be a beam
with a half width of 4-6 mm. The beam will be expanded so that it can
cover a 5 by 1500 meter area on the ocean surface from a typical
altitude of 1500 meters by means of an anamorphic optical element which
has a focal length of -1.5 meters aligned with the flight direction.
This would produce the 5-meter wide slice and a focal length of -7.5 mm
in the other direction to produce the 1000 m cross track illumination.

DEPL:
The brightness of the <u>lidar</u> return is given by the <u>laser</u> energy, and the
highly attenuated scattering from the object, or the water. The
numerical aperture of the light collecting optics is limited practically
to 0.5, (f/1 optics), since the focal length f is equal to the aperture
diameter. The only way to obtain an increased signal is to increase the
detected sample area on the photocathode. For example, if a 30 mm long
photocathode (which could be as narrow as the field-limiting slit) was
used to cover 300 samples over 1500 meters of surface, the focal length
of the optic could only be as large as 17 mm, and the aperture area to
collect the return <u>laser</u> light would only be 2.2 cm.sup.2, which is very
small. Large photocathodes, however, are available in X-ray imaging
tubes and scintillation detectors, and electron optics are capable of
imaging the photoelectrons. At present, there are intensifier tubes with
S-20 300 mm photocathodes which would permit light collecting optics

with aperture areas as great as 220 cm.sup.2 to be used. These
intensifier tubes have a signal strength 100 times greater than the
signal strength of smaller, more readily available, tubes. Thus, the
possibility of building or obtaining a large streak tube which would
utilize the electron optics of larger intensifiers is well within the
state of the art.

CLPV:
laser means for projecting a pulse beam to illuminate a thin segment of
such turbid medium;

CLPV:
means for generating a volume display of said medium utilizing all, or
substantially all, of the reflected portion of said pulse beam; and

CLPV:
generating a volume display of the medium utilizing all, or
substantially all, of the reflected portion of the pulse beam.

CLPV:
means for generating a volume display of the turbid medium in depth
utilizing all, or substantially all, of the reflected portions of the
pulse beam; and

CLPV:
means for generating a volume display of the turbid medium in depth
utilizing all, or substantially all, of the reflected portion of the
pulse beam;

CLPV:
means for processing the composite electronic images, wherein said
sequence of electronic images can be used to produce a corresponding
sequence of composite optical images which can be displayed to show a
motion picture that emulates visual perceptions of travel through the
successive thin sections of turbid ocean volume.

CLPV:
electrooptical means for receiving the electronic-image segments and in
response producing corresponding optical-image segments to display a
composite optical image.

CLPV:
the beam-field-limiting means comprise an anamorphic optical element for
asymmetrically expanding a laser beam with cross-section on the order of
a centimeter to strike an area on the ocean surface of a few meters by
more than one thousand meters.

CLPV:
means for processing the composite electronic images to produce a
corresponding sequence of composite optical images, and for visually
displaying the sequence of composite optical images to show a motion
picture that emulates visual perceptions of travel through the
successive thin sections of turbid ocean volume.

CLPV:
electrooptical means for receiving the electronic-image segments and in
response producing corresponding optical-image segments to display a
composite optical image.

CLPV:
said composite-image processing and sequence-displaying means comprise
means selected from the group consisting of:

CLPV:
said video sequence, displayed by the electronic-image-sequence using
means, includes visible images of:

CLPV:
said video sequence, displayed by the electronic-image-sequence using

means, includes visible images of:

CLPV:
means for processing the composite electronic images, wherein said
sequence of electronic images can be used to produce a corresponding
sequence of composite optical images which can be displayed to show a
motion picture that emulates visual perceptions of travel through the
successive thin sections of turbid ocean volume.

CLPV:
electrooptical means for receiving the composite electronic image and in
response producing corresponding optical-image segments to display a
composite optical image.

CLPV:
visually displaying the multiple composite images sequentially to show a
motion picture that emulates visual perceptions of travel through the
turbid ocean volume along said direction of said shifting step.

CLPV:
displaying the sequence of composite images in human-visible form, as a
motion picture that emulates visual perceptions of travel through the
turbid-ocean-volume.

CLPV:
the distributing step comprises applying the successive substantially
unidimensional electronic signal arrays to control successive
optical-image lines of a two-dimensional display device, to construct
said composite image of the turbid-ocean-volume thin section as a
function of propagation depth.

CLPW:
means for using the sequence of composite electronic images to display a
video sequence that emulates visual perceptions of travel through the
successive thin sections of turbid ocean volume, and

CLPW:
means for recording the sequence of composite electronic images to be
used later in displaying such a video sequence.

CLPW:
a video display for receiving the data array and in response displaying
a corresponding optical image, and

CLPW:
means for recording the data array to be displayed later.

WEST

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Document Number 1

Entry 1 of 2   File: USPT   Nov 10, 1992

DOCUMENT-IDENTIFIER: US 5163062 A
TITLE: Method of frequency shifting using a chromium doped laser
transmitter

BSPR:
Another object is to provide an apparatus and method for improved
optical communications and ranging relying on the hydrogen-beta
Fraunhofer line at 4861.342 Angstroms, a solar hydrogen absorption line
exhibiting at its cusp less than 15 percent the intensity of the average
blue-green solar background and closely corresponding with the peak
transmission wavelength of seawater, making the line particularly useful
for undersea or sea-surface penetrating applications.

DEPR:
Referring now to FIG. 1 of the drawings, a solid state laser transmitter
10 is capable of transmitting on a hydrogen-beta Fraunhofer line at
4861.342 Angstrom or a hydrogen Fraunhofer line at 4340.5 Angstrom when
appropriately tailored in accordance with this inventive concept.
Transmitters operating at these wavelengths are of particular interest
because the daytime background radiation is reduced to less than 15
percent or 18 percent, respectively, of the average blue-green
background by a solar hydrogen absorption line. A Fraunhofer line
transmitter thus has a daytime signal-to-noise ratio that is about six
times higher than an equivalent non-Fraunhofer line laser, an important
factor for lidar and communications applications. The 4861.342 Angstrom
wavelength and 4340.5 Angstrom wavelength are also important in undersea
or sea-surface penetrating applications because they closely correspond
with the wavelength of minimum optical attenuation in blue-ocean
seawater.

DEPR:
Ruby lasers have been commercially available with multimode long-pulse
(hundreds of microseconds) energy levels in the low hundreds of Joules
since the 1960's. Q-switched output is typically 15 percent of the
long-pulse energy. Commercial Q-switched systems have been available
with up to 20 Joules TEM.sub.00 output in 25 nanosecond pulse widths at
low pulse rates. Adding a Q-switch, temperature tuning, and R2 line
selection to a commercially available 15 Joule long-pulse ruby system
(for example an Advanced Laser Systems Inc. Model 604) would provide
multi-Joule TEM.sub.00 pulses of 10 to 20 nanoseconds duration at about
5 pps rate. Raman shifting to the first-Stokes with 40% conversion
efficiency and frequency doubling with 60% conversion efficiency would
result in approximately 500 mJ pulses on the desired Fraunhofer line
wavelength. Considerably lower (by a factor of 10 to 1000) pulse
energies are required for most undersea communications and ranging
applications at these wavelengths. Holding average output power
constant, lower pulse energies would yield correspondingly higher
transmission rates from the same system. The capabilities provided for
undersea communications and ranging in accordance with this inventive
concept are significant.

DEPR:

A Q-switch 14 functions as an optical switching means to spoil resonator Q during buildup of gain medium population inversion and to quickly permit high resonator Q at the desired time of laser emission of the R2 line. The Q-switch permits the gain medium to store a maximum of pump energy before releasing it in a very brief burst with very high peak power. The Q-switch may function as the modulating element for the high peak-power laser ranging and digital communication system when such is the intended use of the system. Q-switches typically employ saturable absorber, electro-optic, acousto-optic, or mechanically rotating optical means. As mentioned above, for pulsed pump sources, Q-switch 14 and pumping source 12 are synchronized to provide maximum oscillator peak power output. Typical Q-switches which could be selected would be the Cleveland Crystals, Inc. of Cleveland, Ohio, Series QX1020 or QX1630 Pockels cells. Alternatively, a Q-switch is provided by R-K Manufacturing Co. of Hollywood, Fla., as an option for the model 6000R-1 ruby laser, a custom version of which lases on the R2 line.

DEPR:
Contemporary optical communication and ranging systems operating in sunlight are improved in performance by utilizing wavelengths at which the solar background illumination is minimized. The invention provides such wavelength transmissions on the hydrogen-beta Fraunhofer line at 4861.342 Angstrom, a solar hydrogen absorption line exhibiting, at its cusp, solar noise less than 15 percent the intensity of the average blue-green solar background. This line also closely corresponds with the peak transmission wavelength of blue-ocean seawater, making it particularly useful for undersea or seasurface penetrating applications. This inventive concept utilizes only a modestly cooled solid-state laser, a room temperature Raman converter and a frequency doubler. It reduces the complexity of contemporary transmitters of this type by not requiring critical milli-Angstrom wavelength control and exotic atomic resonance receivers to reject solar noise as it operates in a multi-Angstrom broad region of minimum solar radiation.

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